

## An Intelligent Control and Virtual Display System for Evolutionary Space Station Workstation Design

by

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### ABSTRACT

Research and development of the Advanced Display and Computer-Augmented Control System (ADCACS) for the space station Body-Ported Cupola Virtual Workstation (BP/VCWS) have been pursued at the Marquette University Advanced Control Technology (ACT) Laboratory. This project explores the potential applications of body-port virtual display and intelligent control technology for the human-system interfacing applications in space station environment. The new system is designed to enable crew members to control and monitor a variety of space operations with greater flexibility and efficiency than existing fixed consoles.

The technologies being investigated include helmet-mounted virtual displays, voice and special command input devices, and microprocessor-based intelligent controllers. Several research topics, such as human factors, decision support expert systems, and wide field of view, color displays are being addressed. A prototype integrated emulator is in development. Our study has demonstrated the significant advantages of this uniquely integrated display and control system, and its feasibility for human-system interfacing applications in the space station command and control environment.

### 1. Introduction

The NASA Space Station Freedom Cupola workstations will play a key role in supporting crew to control and monitor many critical operations and systems in their missions. Examples include station manipulators, flight

telerobotic servicer, station mobile transporter, control of external video and lights, etc. To support these functions, the cupola workstation must support direct or video observations of operations of payloads, docking and berthing, remote inspection of any external point on space station structure, EVA operations, and other operations. Clearly, the performance of display and human-system interface technology in the space station cupola environment directly affect the efficiency and productivity of the space mission, and the crew safety. The cupola workstation must provide a human-system interface for task control and monitoring which accommodates both direct viewing through any of the cupola windows, and remote viewing through any of the space station's video cameras, including those on telerobots, on remotely controllable vehicles, and on the station itself.

The multi-directional viewing requirements indicate that there is a potential for conflict between the spatial orientation of a fixed, or "hard console" cupola workstation and the directions of external tasks. A fixed workstation favors a single direction, while disfavoring other directions. In addition, the need to divide attention between external views and panel mounted displays will create problems for the crew operator. Further disadvantages of permanently installed workstations in the cupola include a potential conflict with the requirement that cupola windows must be replaceable on orbit, since the fixed displays are likely to abut, or even block cupola windows. Currently specified workstations will require multiple displays for each workstation, with a penalty of weight, volume, and power.

The fast growing virtual reality and head-mounted display technologies offer an attractive alternative to the fixed console displays. They are portable, easy to install and

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easy to maintain. In addition, head-mounted display devices and their control processors are compact, lightweight, and low power. This new technology enables the cupola workstation to offer multiple displays, whose visibility depends on head position and orientation tracking. Moreover, the possible applications of state-of-the-art microcomputer hardware and intelligent control technologies in the cupola workstation design open a promising approach which allows the keyboard, control input devices, and audio input/output devices to be body-ported by the crew operator. With all the new ideas described above, a new design concept, called "Body-Ported, Virtual Cupola Workstation (BP/VCWS)", can be formulated.

Use of head-mounted virtual display and intelligent control technologies in the cupola workstation design, however, create new problems that should be solved before physical construction of the BP/VCWS. First, this newly proposed cupola workstation design involves advanced technologies in multi-disciplines, including a helmet-mounted virtual display device, voice and special command input devices, and microprocessor-based intelligent controllers. Several research topics, such as human factors, decision support expert systems, and wide field of view, color displays must also be addressed. Moreover, the effectiveness and user acceptance of such a device is another key issue.

Most head-mounted display technologies, which are currently available for application to the space station has been in use for aviation. Representative systems developed for use in combat rotorcraft or fighter aircraft include the Honeywell Integrated Helmet and display Sight System (HADSS). Two systems developed for use as visual systems for flight simulators are the Visually Coupled Airborne Systems Simulator (VCASS), developed at Wright-Patterson AFB, OH, and the Fiber-Optic Helmet Mounted Display (FOHMD), developed at Williams AFB, AZ. All of these systems have been developed for specific application environments which are very different from that of the space station. For example, there is no need of a crash helmet during missions on board the space station, so the integration of a display into a helmet is of little use. The tradeoffs required for such integration are inappropriate for application to space station. The simulator displays, on the other hand, are very bulky and would be unacceptable as flight equipment.

NASA has two head-mounted display activities that are relevant to the current Advanced Development effort. One project is the development at JSC of prototype displays for use inside EVA helmets. The EVA helmet display has considerable power constraints which limit the design options. Further, the information to be presented on the

EVA display is of far less complexity than the potential IVA display. Overall, the design goals of the IVA system would not be met by the EVA system. The other NASA project is the development at ARC of low-cost, wide field-of-view head-mounted displays for laboratory research in Virtual Environment Display (VIVED). This system does not provide the see-through display capability which will be required on the space station. Further, the ARC system provides a very wide instantaneous visual field-of-view at the expense of resolution, which is the opposite of the design tradeoff needed for the space station display.

The research and development effort for such a BP/VCWS system has already been pursued at the Marquette University Advanced Control Technology (ACT) Laboratory. The research project, "Advanced Display and Computer-Augmented Control System (ADCACS)", is sponsored by NASA Ames research center and includes the participation of Astronautics Corporation of America. The project motivates the exploration of the potential applications for the virtual display and intelligent control technologies especially in the space station environment. The new system will be designed to enable crew members to control and monitor a variety of space operations with greater flexibility and efficiency than existing fixed consoles.

The technologies being investigated include helmet-mounted virtual displays, voice and special command input devices, and microprocessor-based intelligent controllers. Several research topics, such as human factors, decision support expert systems, and wide field of view, color displays are being addressed. A prototype integrated emulator is in development. Our study has demonstrated the significant advantages of this uniquely integrated display and control system, and its feasibility for human-system interfacing applications in the space station command and control environment.

## **2. ADCACS Project Overview**

The Advanced Display and Computer Augmented Control System (ADCACS) was proposed as a three-year systems engineering project that is devoted to the research and development of such an advanced human-system interface device, i.e., the Body-Ported Virtual Cupola Workstation (BP/VCWS). This project takes advantage of other closely related on-going projects that are critical and very important to the success of the project.

### **Objectives**

Specifically, the overall objectives of the ADCACS project are:

- 1) to demonstrate the feasibility of the Body-Ported Cupola Workstations (BP/VCWS) meeting the needs of the baseline and evolutionary Space Station Freedom (SSF) Cupola Workstations;
- 2) to initiate an engineering approach to construct such a BP/VCWS, and through evolution, to replace existing "hard console" cupola workstation design;
- 3) to develop a flight-qualifiable prototype BP/VCWS, and to significantly advance the general state-of-the-art in workstation technology including virtual reality" and intelligent Control.

### Evolutionary Approach

The above goals were planned to be accomplished in the three-year project that was scheduled in three phases. The Phase one research, started July 1, 1990 and ended June 30, 1991, has been carried out at the Marquette University Advanced Control Technology (ACT) Laboratory, with participation of Astronautics Corporation of America (ACA). During the Phase One research, it was necessary and important to establish an evolutionary approach toward the physical construction of the flight-qualifiable BP/VCWS, starting from the requirements and feasibility analysis to the construction and evolution of on-ground emulators. A variety of factors were taken into account.

The evolutionary steps can be described as:

- 1) to define requirements and configurations for the BP/VCWS that are consistent with crew user requirements and Space Station Program constraints;
- 2) to study the relevant technologies, that will be applied to the proposed body-ported virtual display and knowledge-based intelligent control system, through literature search and laboratory experimental investigations; and
- 3) to build the prototype emulator, and later build the Full-Function Emulator (FFE), based on the prototype emulator for further studies of technology readiness of flight-qualifiable BP/VCWS.

## 3. Description of the Prototype Emulator System

### 3.1 Overview of the Virtual Workstation Emulator

A prototype emulator for the virtual display and intelligent system has been designed and built during the first year.

This emulator environment consists of an IBM-386 compatible personal computer (PC1), an IBM-286 compatible personal computer (PC2), and a Silicon Graphics Personal IRIS workstation (IRIS). The IRIS, model 4D/35TG has a 35MHZ CPU. This architecture is shown in Figure 1.

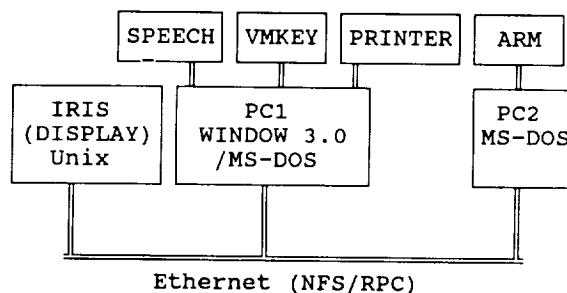


Figure 1 Overview of the Prototype Emulator Environment

As shown in Figure 1, the PC1 is dedicated to the intelligent control and voice command input experiments, and PC2 is used for acquiring and processing data from the fingers/hand/arm position sensing input devices. The IRIS is used for the graphic generation of the virtual scenario elements to be manipulated. The entire system is networked together using an Ethernet LAN. This prototype emulator can perform the following experiments:

- 1) virtual tele-robot arm/hands display and control;
- 2) voice command input;
- 3) force-based arm and position-based master command input and control;
- 4) knowledge-base intelligent control and decision support system testing and implementation.

### 3.2 Networking

For inter-process communication over the Ethernet LAN, the "Sockets" protocol was chosen for the ADCACS application. RPC (remote procedure call) and NFS (network file system) were also evaluated as options to sockets.

Internet Domain Stream Sockets was chosen for its simplicity in satisfying the ADCACS project needs. With proper programming, all subsystems can process data concurrently. Any subsystem may be a client or a server. This increases the flexibility of the entire emulator. Minimal overhead is required since sockets is a fairly low level communications technique.

### 3.3 Graphics Generation

Graphical generations for virtual environment and virtual tele-robot are performed on the Cilison Graphics IRIS workstation. This machine is fast enough to generate the real-time (no perceivable delay) images necessary for the present research. It is anticipated that as the complexity of the control scenarios increases, the graphical image generation power will have to be increased.

The primary graphics program in use at the present time is "armbox.c". It uses the Silicon Graphics standard graphics library, GL. GL is a set of C callable subroutines. The subset of routines being used in "armbox.c" includes: 1) a variety of viewing windows; 2) a single infinite light source (multiple infinite and local lighting source models are available for experimentation and require increased processing time); 3) RGB mode and Gouraud shading for realistic shading with fewer polygons as compared with flat shading; 4) double buffering to synchronize rendering with the screen so smooth motion exists with no flickering; 5) backface removal and z-buffering to decrease rendering time for hidden surface removal; 6) viewing matrix manipulation and stack routines to easily and quickly position graphical elements; 7) queues for internal events and standard input devices; and 8) simple 3 dimensional polygon rendering routines.

The program routine "armbox.c" renders a picture of a right arm, including a hand and fingers using positioning data received over the network. It also has techniques for drawing boxes in any location and orientation. For iteration experimentation of the graphics portion of the emulator, a second process may be run on the Personal IRIS which emulates a microcomputer sending data to the IRIS.

For the networking setup, the IRIS is the client and PC2 is the server. The main graphic loop requests positioning data from the server. It then immediately renders a picture using initial data. After rendering the picture, it reads the data sent from the server and loops. The second time through the loop it again requests data from the server and immediately renders a picture, this time with the previous data. Each time through the loop the picture is rendered using the previous data. This technique allows the graphic generation to be performed in parallel with the acquiring and preprocessing of the positioning data.

The screen is refreshed at 60 Hz so there is no perceivable flicker. The image update time appears to be slower than 60 Hz. Until the next image is generated, the IRIS simply re-displays the same image. For the same 3

dimensional model, the image generation time will differ depending on the depicted position of the virtual arm.

Collision detection has been successfully completed for boxes in any orientation. In addition to drawing an arm, several boxes are also drawn within arm's reach. The location of the tip of each finger is compared to the location of a box resulting in a Boolean array of collision locations. Additional points on the fingers, hand, or arm may be identified as important for collision detection and added to the Boolean array. This may be done for any number of boxes.

Once the collision detection data is acquired, decisions will be based on the data. These decisions could include coloring the appropriate box, limiting motion of the moving object (a finger presently), or grabbing and moving one of the boxes. If these decisions are simple and need to be made quickly, they could be performed internal to the IRIS. If they are complex and could be made with a longer time delay, it may be appropriate to off-load the decision process to another processor on the network to preserve processing time on the IRIS for complex graphical generation. The decision processor could be running a knowledge-based software package.

The present collision information is used to draw the appropriate box with a color that is dependent on which finger is touching the box. This gives the operator clear visual feedback.

Also, a virtual space cupola environment model has been developed on the IRIS for environmental and space operation monitoring purposes. This model is connected to the knowledge-based system on PC1 through Ethernet Link.

### 3.4 Master Command Input Devices

#### Force-Based Master Arm

A force-based master arm controls the prototype emulator environment. The arm controller utilizes 5 degrees-of-freedom on the arm (i.e. shoulder flexion/extension, shoulder abduction/adduction, upper arm rotation, elbow flexion/extension, and forearm rotation) with near future goals of wrist flexion/extension and wrist abduction/adduction. The current configuration consists of the force-based arm as an input device which sends an analog signal to an A/D board and the interpretation software in a 286-based microcomputer (PC@). This computer reads a digital signal from the 5 degrees-of-freedom on the arm and maps it to a range of motion for the virtual arm. This information is then sent across a

distributed network to the graphics workstation via Internet Domain Stream Sockets. This data is read by the graphics terminal and is used to adjust the position of the virtual human arm that is graphically portrayed.

The interpretation that occurs at PC2 consists of scaling the digital output of each channel to a range of motion. This is accomplished through the utilization of a physiological data base called Ergobase by Biomechanics Corporation of America. This data base contains the range of motion for each degree-of-freedom that is addressed by the force-based arm. Ergobase contains the ranges of motion in degrees for the above specified movements for the central 95 percentile of the population. By linearly transforming the digital output of the force-based sensor to an angle degree that is within the human range of motion for the specific joint, a truly anthropomorphic graphical arm in the virtual world results.

The prototype emulator has been created with optimum anthropomorphic and human factor considerations at every step of its design. The design of virtual scenario presentation will be dependent on calculations and analysis of optimal human range of motion.

### Position-Based Master (PBM) Hand

The position based master (PBM) hand has been successfully added to the fingers/hand/arm position data processing microcomputer to complement the force-based arm. Each joint of the PBM hand has an associated potentiometer (pot). The resulting voltage signal from each pot (some limited range within 0 to 5 volts) is sent through a two stage operational amplifier circuit. The first stage isolates the signal from the rest of the circuit. This is useful since it essentially eliminates any effects of unmatched pot and wire resistances in the PBM. The second stage has two adjustable pots. One is for gain and the other is for level shifting so that the resulting voltage ranges from 0 to 5 volts. The output of the second stage is properly conditioned for the full range of the analog-to-digital converter.

### 3.5 Knowledge-Based Intelligent Control

One 386-based personal computer is dedicated for experimental investigations of knowledge-based intelligent display system control and the decision support systems. A microcomputer-based speech recognition system, Voice Master Key produced by Convex, Inc., was successfully installed at the beginning of the ADCACS project. A 386 microcomputer is designated for intelligent expert system control to the speech recognition system. Based on PC1 and communication facilities through LAN, the expert

system shell, called "Nexpert Object", is used for the following two intelligent control experiments:

- 1) A Prototype KBS Control System (see Figure 2 for details), and

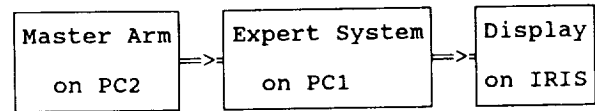


Figure 2a: Control of Data Flow from Master Arm to IRIS

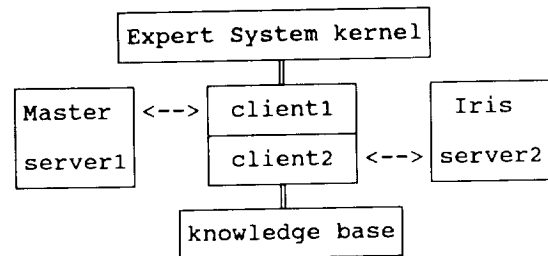


Figure 2b: Control Signal Diagram

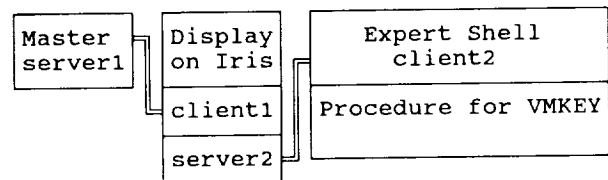


Figure 2c: Display Synchronization Diagram

- 2) A simple control system that is based on a time-sequential control strategy, which uses several procedures implemented by one process in PC1. The calling out function of Expert will be used, which refers to the ability of an expert system application to call user written functions or library routings. The knowledge-based Expert System Shell was used to infer the production rules in the knowledge base for data validity checking and intelligent controlling. Also the data transform and inter-procedure communications were implemented under the Knowledge-Based System.

### 3.6 Voice Command Input Devices

#### The Voice Master Key (VMKey)

VMKey (Version 2.0) is a voice control device made by CONVOX INC., which can be used to train and control computers to accept commands in simple spoken English or any other languages. VMKey comes in two parts: the hardware "ear" and the software "brain". The "ear" is a combination headset earphone/microphone plus a plus-in card. This device allows the user to run an application program with voice commands.

#### Voice Command Process Control

The following voice command input functions have been implemented:

- 1) VMKEY was used to accept the control interface signals;
- 2) VMKey has been Integrated into the Expert System; and
- 3) The SPEECH Input Device has been employed to demonstrate the voice warning functions.

### 4. Conclusions

The design and development of the prototype emulator implements the first step of the evolutionary approach towards the construction of the proposed BP/VCWS system. Since this emulator is only a prototype, it has limited functions. Future work with the goal of improving the emulator includes integration of wide-field-of-view optical devices, implementation of stereoscopic display devices, and simulation of operational warning and caution systems. However, this prototype emulator establishes a solid foundation for the construction of the full function emulator for more intensive technical investigation of the proposed BP/VCWS.

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